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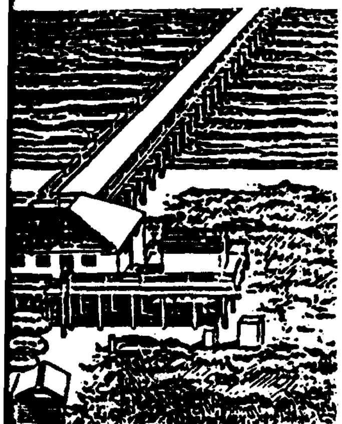
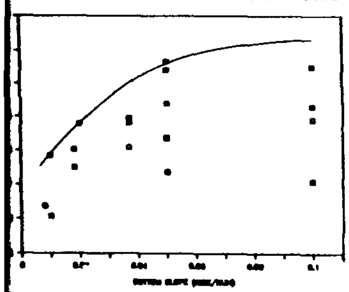


RELATIVE WAVE HEIGHT VS BOTTOM SLOPE



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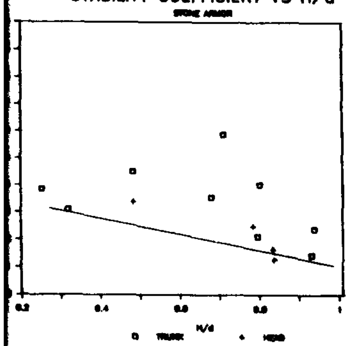

TECHNICAL REPORT CERC-92-2

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USE OF SITE-SPECIFIC MODEL DATA FOR GENERAL BREAKWATER DESIGN

by

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Coastal Engineering Research Center

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this investigation was to obtain a better understanding of why significant variations in the stability coefficient occur. Specifically, it was hoped that functional relationships could be developed between the stability coefficient and such variables as wave height, wave period, and water depth. These functional relationships would then be used as input to an improved procedure for obtaining minimum armor unit weights required for hydraulic stability. Also, it was hoped that a link could be developed between breaking and nonbreaking wave test results.

Based on results of model tests described herein, in which tetrapod, tribar, dolos, and stone armor are used on breakwater trunks and heads, it is concluded that test results are very significant in that they show tetrapod, tribar, dolos, and stone stability to be dependent on the combined effects of wave height, wave period, and water depth with minimum stability occurring at the lower values of d/L and higher values of H/d, i.e., longer wave periods in shallower water. An improved procedure for determining minimum armor unit weights was developed.

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Armor stability, Dolos armor, Stone armor, Tribar armor, Breakwaters, Rubble mound, Tetrapod armor

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PREFACE

Authority for the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to conduct this study was granted by the Headquarters, US Army Corps of Engineers (HQUSACE), under Work Unit 32534, "Breakwater Stability - A New Design Approach," of the Coastal Structure Evaluation and Design Program, Coastal Engineering Area of Civil Works Research and Development. The HQUSACE Technical Monitors for this research were Messrs. John H. Lockhart, Jr.; John G. Housley; James E. Crews; and Robert H. Campbell. The CERC Program Managers were Dr. C. Linwood Vincent and Ms. Carolyn M. Holmes.

The study was conducted by personnel of CERC under the general direction of Dr. James R. Houston, Chief, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC. Direct supervision was provided by Messrs. C. E. Chatham, Chief, Wave Dynamics Division (WDD), and D. Donald Davidson, Chief, Wave Research Branch (WRB), WDD. This report was prepared by Mr. Robert D. Carver, Principal Investigator, and Mrs. Brenda J. Wright, Engineering Technician, WRB. This report was typed by Ms. Myra E. Willis, WRB, and edited by Ms. Lee T. Byrne, Information Technology Laboratory, WES.

Dr. Robert W. Whalin was Director during the publication of this report. COL Leonard G. Hassell, EN, was Commander and Deputy Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
tons (2,000 pounds, mass)	907.1847	kilograms

USE OF SITE-SPECIFIC MODEL DATA FOR GENERAL BREAKWATER DESIGN

PART I: INTRODUCTION

Background

1. During the past decade, much consternation has arisen in the international coastal engineering community over the use of the Hudson Stability Equation (Shore Protection Manual (SPM) 1984). This is not surprising if one accepts the fact that, based on the present state of the art, this approach to breakwater design is an oversimplification of a complex problem. Most researchers have the highest respect for the pioneering work accomplished by Hudson during the 1950's and 1960's; however, based on a detailed study of the original work, numerous conversations with Mr. Hudson, and an attempt to understand the physics of the problem, it has been concluded that the present formula does not necessarily address all design parameters. Since the stability coefficient (K_D) combines the effects of over 20 wave and structure variables, it is reasonable to expect that K_D may vary from one investigation to another (as confirmed by recent laboratory tests).

2. Information from many US Army Engineer Waterways Experiment Station (WES) site-specific breakwater stability studies exists, but has never been generalized and summarized to the extent possible due to the narrow focus of individual projects. In the aggregate, the stable plans developed in these studies cover a significant range of wave heights, wave periods, water depths, and bottom slopes. Also, many of these studies used the maximum breaking wave condition for a given water depth, wave period, and offshore slope. This condition has not been parameterized, but it is similar to the maximum wave conditions shown in the SPM.

Purpose of Study

3. The purpose of this investigation was to obtain a better understanding of why significant variations in the stability coefficient occur. Specifically, the objective was to develop functional relationships between the stability coefficient and such variables as wave height, wave period, and water depth. These functional relationships then would be used as input to an

improved procedure for determining minimum armor unit weights required for hydraulic stability. Also, a link was sought between breaking and nonbreaking wave test results.

Approach

4. Previous breakwater stability investigations conducted by Carver (1983) and Carver and Wright (1988a, 1988b, and 1988c) have shown that the relative depth (d/L) and relative wave height (H/d) are two of the most important dimensionless variables influencing breakwater stability. Therefore, results of the site-specific studies described herein were nondimensionalized relative to these and other pertinent variables that characterize incident wave conditions.

PART II: RESULTS OF ARMOR STABILITY ANALYSIS

General

5. A review of WES reports yielded 28 site-specific, stability studies conducted between 1955 and 1988. These studies, conducted with regular waves, are summarized by date, armor type, location, and investigator(s) in Table 1. It is interesting to note that all tests were conducted using tetrapods, tribars, dolos, or stone. Tetrapods and tribars were considered during the period 1955-1971, whereas all studies conducted since 1971 have used either dolos or stone armor. Tables 2-5 summarize important project characteristics such as armor weight, water depth, design wave period and height, and bottom slope (seaward of the structure) for each of the four armor types tested.

6. Trial plots of the stability coefficient K_D as a function of deep water (H/L_o) and local wave steepness (H/L), deep water (d/L_o) and local relative depth (d/L), and local relative wave height (H/d) were made. The plots showed the stability coefficient to be best correlated by d/L and H/d; therefore, these variables were chosen as the basis on which to build a new design procedure.

Tetrapod Design

7. Figures 1 and 2 present K_D as a function of d/L and H/d, respectively. These data show tetrapod stability to be influenced by both parameters with minimum stability being observed at the lower values of d/L and higher values of H/d, i.e., longer wave periods in shallower water. The tetrapod data set is not sufficient to develop general design curves; however, significant future interest in tetrapods is not anticipated with the advent of newer, hydraulically superior, armor units.

Tribar Design

8. Figures 3 and 4 present tribar stability as a function of d/L and H/d, respectively. Again, minimum stability is observed for the longer wave periods in shallower water. It is suggested that tribar armor be sized by entering these plots with the appropriate values of d/L and H/d and using

the minimum stability coefficient thus obtained.

Dolos Design

9. Figures 5 and 6 show dolos stability to also be strongly influenced by d/L and H/d. Again, it is suggested that the lower limit curves be used to determine minimum hydraulic stability.

Stone Design

10. Lower limit design curves for stone armor are presented as a function of d/L and H/d in Figures 7 and 8, respectively. Minimum trunk and head stabilities proved to be similar. Therefore, only one design curve for both trunks and heads is presented.

Discussion

11. Results presented herein are very significant in that they show tetrapod, tribar, dolos, and stone stability to be dependent on the combined effects of wave height, wave period, and water depth with minimum stability occurring at the lower values of d/L and higher values of H/d, i.e., longer wave periods in shallower water. Use of the design curves presented in Figures 1-8 should provide a refinement over the procedures presently given in the SPM.

PART III: PREDICTION OF MAXIMUM BREAKING WAVE HEIGHTS

12. Experience in conducting model studies of the type summarized herein has shown that breaking wave heights may significantly exceed 0.78d, depending on bottom slope and wave period. Figure 9, developed from data given in Tables 2-5, presents H/d as a function of bottom slope. A correlation with wave period could not be developed, due to the limited range of periods investigated. However, the upper limit curve (Figure 9) should provide a good estimate of the maximum breaking wave heights that can be expected for the range of wave periods that are typically considered in design of breakwaters.

PART IV: DESIGN CURVE USE

Example Problem 1

Description

13. The selected structure is a breakwater trunk with stone armor having a unit weight of 165 pcf.* Sufficient wave energy exists to cause breaking waves at the structure toe. The bottom approach slope is about 1V:100H. Water depth at the toe is 20 ft, the wave period is 14 sec, and the armor slope is 1V:2H.

Design curve use

14. Using the water depth at 20 ft and the bottom slope of 0.01, Figure 9 indicates an H/d of 0.80, thus yielding a 16-ft design wave height. Calculate L_o, d/L_o, and d/L:

$$L_o = \frac{gT^2}{2\pi} = \frac{(32.17)(14)^2}{2\pi} \approx 1{,}004 \text{ ft} \tag{1}$$

$$d/L_o = 20/1{,}004 = 0.01992$$

Thus,

$$d/L = 0.0575 \tag{2}$$

Figures 7 and 8 yield a minimum stability coefficient of 1.4 for the selected design conditions. The stable armor weight W_a is determined from the Hudson formula, i.e.,

$$W_a = \frac{\gamma_a H^3}{K_D(S_a - 1)^3 \cot\alpha}$$

$$W_a = \frac{165(16)^3}{1.4(165/64 - 1)^3 2} \tag{3}$$

$$W_a = 61{,}400 \text{ lb}$$

Thus, the use of 31-ton stone is recommended.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Example Problem 2

Description

15. The same structure and wave conditions described in Paragraph 14 apply; however, an alternate design using dolos armor is desired. The dolos unit weight is assumed to be 150 pcf.

Design curve use

16. Using $d/L = 0.0575$ and $H/d = 0.80$ in concert with Figures 5 and 6 gives a minimum stability coefficient of 11. Again, application of the Hudson formula yields

$$W_a = \frac{\gamma_a H^3}{K_D (S_a - 1)^3 \cot\alpha}$$

$$W_a = \frac{150(16)^3}{11(150/64 - 1)^3 2} \tag{4}$$

$$W_a = 11{,}500 \text{ lb}$$

The use of 6-ton dolos is recommended if the alternate design is chosen.

PART V: CONCLUSIONS

17. Based on the results of the site-specific model tests described herein in which tetrapod, tribar, dolos, and stone armor are used on breakwater trunks and heads, it is concluded that:

a. Test results are very significant in that they show tetrapod, tribar, dolos, and stone stability to be dependent on the combined effects of wave height, wave period, and water depth with minimum stability occurring at the lower values of d/L and higher values of H/d, i.e., longer wave periods in shallower water.

b. Figures 1-8 provide a means of linking breaking and nonbreaking wave test results; i.e., they cover a range of H/d and d/L encountered for both types of waves.

c. The design procedure illustrated in Part IV should provide a refinement over the approach presently given in the SPM.

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Table 1

Summary Of Site-Specific Studies

Armor Type	Location	References
Tetrapod	Crescent City, CA	Hudson and Jackson (1955)
Tetrapod	Crescent City, CA	Hudson and Jackson (1956)
Tribar	Nawiliwili, HI	Jackson, Hudson, and Housley (1960)
Stone	Siuslaw, OR	US Army Engineer Waterways Experiment Station (1963)
Tribar	Kahului, HI	Jackson (1964)
Tetrapod	Nassau, Bahamas	Jackson (1965)
Stone	Dana Point, CA	Dai and Jackson (1966)
Tribar	Nassau, Bahamas	Hudson and Jackson (1966)
Tetrapod	Noyo, CA	Jackson (1966)
Stone	Burns Harbor, IN	Jackson (1967)
Tribar	Monterey Harbor, CA	Davidson (1969)
Tribars and Dolos	Humboldt Bay, CA	Davidson (1971)
Dolos	Wainae, HI	Bottin, Chatham, and Carver (1976)
Stone and Dolos	Lahaina, HI	Carver (1976)
Dolos	Jubail Harbor, Saudi Arabia	Carver and Davidson (1976)
Stone	Masonboro Inlet, NC	Carver and Markle (1978)
Dolos	Nawiliwili, HI	Davidson (1978)
Stone	Tillamook, OR	Markle and Davidson (1979)
Dolos	Maalaea, HI	Carver and Markle (1981a)
Stone	Port Ontario, NY	Carver and Markle (1981b)
Stone	San Juan, Puerto Rico	Markle (1981)
Dolos	Kahului, HI	Markle (1982)
Stone and Dolos	Oregon Inlet, NC	Carver and Davidson (1983)
Stone	Mission Bay, CA	Markle (1983)
Stone	San Pedro, CA	Carver (1984)
Dolos	Crescent City, CA	Baumgartner, Carver, and Davidson (1985)
Stone	San Pedro, CA	Baumgartner, et al. (1986)
Stone	St. Paul, AK	Ward (1988)

Table 2

Summary of Results of Tetrapod Armor

Armor Height tons	Armor Specific Weight pcf	Bottom Slope	Cot	d, ft	T, sec	H, ft	K_D	Breaking Waves	Angle of Attack deg	Section of Structure	L_o	d/L_o	H/L_o	H/d	L	d/L	H/L
								Crescent City, CA									
17.60	140	Flat	2.000	69.0	14	23.0	14.4	No	90.0	Trunk	1004	0.069	0.023	0.333	613	0.1126	0.0375
17.60	140	Flat	3.000	69.0	14	25.0	12.4	No	90.0	Trunk	1004	0.069	0.025	0.362	613	0.1126	0.0408
17.60	140	Flat	4.000	69.0	14	26.0	10.4	No	90.0	Trunk	1004	0.069	0.026	0.377	613	0.1126	0.0424
25.00	150	Flat	1.333	55.0	14	20.0	7.4	No	90.0	Trunk	1004	0.055	0.020	0.364	555	0.0990	0.0360
								Noyo Harbor, CA									
36.00	150	Flat	3.000	48.0	14	29.0	7.0	Yes	90.0	Trunk	1004	0.048	0.029	0.604	523	0.0918	0.0555
								Nassau Harbor, Bahamas									
7.00	150	Flat	1.500	25.0	11	12.0	5.1	No	90.0	Head	620	0.040	0.019	0.480	299	0.0836	0.0401
14.00	150	Flat	1.500	25.0	11	15.0	5.0	No	90.0	Head	620	0.040	0.024	0.600	299	0.0836	0.0502
17.00	150	Flat	1.500	25.0	11	16.0	5.0	No	90.0	Head	620	0.040	0.026	0.640	299	0.0836	0.0535
								Humboldt Bay, CA									
28.00	150	1:10	5.000	43.0	16	23.0	2.7	No	90.0	Head	1311	0.033	0.018	0.535	575	0.0748	0.0400

Table 3

Summary of Results for Tribar Armor

Armor Height tons	Armor Specific Weight pcf	Bottom Slope	Cot	d, ft	T, sec	H, ft	K_D	Breaking Waves	Angle of Attack deg	Section of Structure	L_o	d/L_o	H/L_o	H/d	L	d/L	H/L
								Morro Bay, CA									
20.00	150	1:50	1.5	38.0	13	24.0	14.2	No	90.0	Trunk	865	0.044	0.028	0.632	434	0.0876	0.0553
								Nassau Harbor, Bahamas									
10.00	150	Flat	1.5	25.0	11	19.0	14.1	Yes	90.0	Trunk	620	0.040	0.031	0.760	299	0.0836	0.0636
19.00	150	Flat	1.5	30.0	11	23.0	13.2	Yes	90.0	Trunk	620	0.048	0.037	0.767	325	0.0924	0.0709
								Kahului Harbor, Maui									
35.00	156	1:125	2.0	58.0	18	37.0	19.0	Yes	90.0	Trunk	1659	0.035	0.022	0.638	749	0.0774	0.0494
35.00	146	1:27	3.6	42.0	18	34.0	10.8	Yes	90.0	Trunk	1659	0.025	0.020	0.810	644	0.0652	0.0528
19.00	146	1:27	2.6	29.0	18	25.6	11.8	Yes	90.0	Trunk	1659	0.017	0.015	0.883	540	0.0537	0.0474
10.00	146	1:27	2.0	24.0	18	21.5	17.2	Yes	90.0	Trunk	1659	0.014	0.013	0.896	493	0.0487	0.0436
35.00	156	1:125	3.0	58.0	14	30.0	6.8	No	90.0	Head	1004	0.058	0.030	0.517	569	0.1020	0.0528
50.00	156	1:125	4.0	58.0	18	35.0	5.6	No	90.0	Head	1659	0.035	0.021	0.603	749	0.0774	0.0467
35.00	156	1:125	3.0	58.0	18	36.0	11.7	No	50.0	Head	1659	0.035	0.022	0.621	749	0.0774	0.0480
50.00	156	1:125	3.0	58.0	18	36.0	8.2	No	50.0	Head	1659	0.035	0.022	0.621	749	0.0774	0.0480
								Nawilihili Harbor, Hawaii									
17.80	158	1:55	1.5	32.0	16	24.0	12.9	Yes	90.0	Trunk	1311	0.024	0.018	0.750	500	0.0639	0.0480
								Humboldt Bay, CA									
23.00	150	1:10	5.0	43.0	16	29.0	6.6	No	45.0	Head	1311	0.033	0.022	0.674	575	0.0748	0.0504
33.00	150	1:10	5.0	43.0	16	36.0	8.7	No	45.0	Head	1311	0.033	0.027	0.837	575	0.0748	0.0626
44.00	150	1:10	5.0	43.0	16	36.0	6.6	No	45.0	Head	1311	0.033	0.027	0.837	575	0.0748	0.0626

Table 4

Summary of Results for Dolos Armor

Armor Height tons	Armor Specific Weight pcf	Bottom Slope	Cot	d, ft	T, sec	H, ft	K_D	Breaking Waves	Angle of Attack deg	Section of Structure	L_o	d/L_o	H/L_o	H/d	L	d/L	H/L
							Lahaina Harbor, Hawaii										
0.75	150	1:20	2.0	7.5	16	8.0	10.6	Yes	90.0	Trunk	1311	0.006	0.006	1.067	247	0.0304	0.0324
							Maalaea Harbor, Maui, Hawaii										
6.00	147	1:50	1.5	19.0	16	16.7	17.4	Yes	90.0	Trunk	1311	0.014	0.013	0.879	390	0.0488	0.0429
							Waianae Harbor, Oahu, Hawaii										
1.50	150	1:20	2.0	16.0	16	11.8	16.9	Yes	90.0	Trunk	1311	0.012	0.0009	0.738	358	0.0446	0.0329
							Kahului, Maui Hawaii										
30.00	146	1:100	1.7	49.0	18	29.8	18.0	Yes	90.0	Trunk	1659	0.030	0.018	0.608	693	0.0707	0.0430
							Nawiliwili Harbor, Hawaii										
2.00	146	1:10	1.5	10.0	16	8.9	8.2	Yes	90.0	Trunk	1311	0.008	0.007	0.890	285	0.0351	0.0313
							Oregon Inlet, North Carolina										
9.50	150	1:20	1.5	16.5	15	15.5	8.1	Yes	90.0	Trunk	1152	0.014	0.013	0.939	340	0.0485	0.0455
14.00	150	1:20	3.0	28.0	15	22.0	7.8	No	45.0	Head	1152	0.024	0.019	0.786	439	0.0638	0.0501
14.00	150	1:20	3.0	21.0	15	17.6	4.0	Yes	0.0	Head	1152	0.018	0.015	0.838	383	0.0549	0.0460
14.00	150	1:20	3.0	21.0	15	17.6	4.0	Yes	22.5	Head	1152	0.018	0.015	0.838	383	0.0549	0.0460
14.00	150	1:20	3.0	21.0	15	17.6	4.0	Yes	45.0	Head	1152	0.018	0.015	0.838	383	0.0549	0.0460
14.00	150	1:20	3.0	21.0	15	17.6	4.0	Yes	67.5	Head	1152	0.018	0.015	0.838	383	0.0549	0.0460
14.00	150	1:20	3.0	21.0	15	17.6	4.0	Yes	90.0	Head	1152	0.018	0.015	0.838	383	0.0549	0.0460
14.00	150	1:20	3.0	23.0	15	19.2	5.2	Yes	45.0	Head	1152	0.020	0.017	0.835	400	0.0576	0.0480
							Atlantic Station, New Jersey										
43.00	150	1:10	2.0	56.3	16	40.0	23.0	Yes	90.0	Trunk	1311	0.043	0.031	0.710	651	0.0865	0.0615
62.00	150	1:10	3.0	56.3	16	40.0	10.6	Yes	Var	Head	1311	0.043	0.031	0.710	651	0.0865	0.0615
							Jubail Harbor, Saudi Arabia										
5.50	150	Flat	2.0	29.5	9	15.4	10.3	No	54.0	Head	415	0.071	0.037	0.522	257	0.1149	0.0600
5.50	150	Flat	2.0	29.5	9	15.4	10.3	No	68.0	Head	415	0.071	0.037	0.522	257	0.1149	0.0600
							Humboldt Bay, California										
45.00	155	1:10	5.0	43.0	16	40.0	7.7	Yes	45.0	Head	1311	0.033	0.031	0.930	575	0.0748	0.0696

Table 5

Summary of Results for Rough Angular Stone Armor

Armor Height tons	Armor Specific Weight pcf	Bottom Slope	Cot	d, ft	T, sec	H, ft	K_D	Breaking Waves	Angle of Attack deg	Section of Structure	L_o	d/L_o	H/L_o	H/d	L	d/L	H/L
								Burns Habor, IN									
13.50	165	1:100	1.5	47.0	11	15.0	3.1	No	90.0	Trunk	620	0.076	0.024	0.319	394	0.1193	0.0381
								Long Beach (Sohio), CA									
7.50	165	Flat	2.0	55.4	13	14.0	3.8	No	90.0	Trunk	865	0.064	0.016	0.253	512	0.1081	0.0273
								Mission Bay, CA									
14.50	165	Flat	1.5	34.6	9	16.7	4.5	No	90.0	Trunk	415	0.083	0.040	0.483	274	0.1262	0.0609
14.50	165	Flat	1.5	34.6	15	16.7	4.5	No	90.0	Trunk	1152	0.030	0.014	0.483	485	0.0714	0.0344
14.50	165	Flat	2.0	34.6	9	16.7	3.4	No	33.0	Head	415	0.083	0.040	0.483	274	0.1262	0.0609
14.50	165	Flat	2.0	34.6	15	16.7	3.4	No	33.0	Head	1152	0.030	0.014	0.483	485	0.0714	0.0344
								Morro Bay, CA									
25.00	175	1:50	2.25	38.0	15	27.0	5.9	No	90.0	Trunk	1152	0.033	0.023	0.711	507	0.0750	0.0533
								Lahaina Harbor, HI									
2.75	170	1:20	2.00	7.5	16	8.0	1.7	Yes	90.0	Trunk	1311	0.006	0.006	1.067	247	0.0304	0.0324
								Jubail Harbor, Saudi Arabia									
7.15	165	1:10	2.00	19.7	9	13.4	3.5	Yes	90.0	Trunk	415	0.048	0.032	0.680	215	0.0914	0.0622
								Port Ontario Harbor, NY									
5.30	155	1:50	2.00	12.3	11	9.8	2.1	Yes	90.0	Trunk	620	0.020	0.016	0.797	214	0.0574	0.0457
								San Juan, Puerto Ric.									
33.90	165	1:20	2.00	22.9	17	23.3	3.9	Yes	90.0	Trunk	1480	0.015	0.016	0.017	454	0.0504	0.0513
27.70	165	1:20	2.00	26.9	17	28.0	8.3	Yes	72.0	Head	1480	0.018	0.019	1.041	491	0.0548	0.0571
27.70	165	1:20	2.00	26.9	17	28.0	8.3	Yes	42.0	Head	1480	0.018	0.019	1.041	491	0.0548	0.0571
								Masonburo Inlet, NC									
18.00	165	1:20	2.00	14.5	15	13.5	1.4	Yes	90.0	Trunk	1152	0.013	0.012	0.931	320	0.0453	0.0422
								Oregon Inlet, NC									
22.00	165	1:20	1.5	16.5	15	15.5	2.4	Yes	90.0	Trunk	1152	0.014	0.013	0.939	340	0.0485	0.0455
30.00	165	1:20	3.0	28.0	15	22.0	2.5	No	45.0	Head	1152	0.024	0.019	0.786	439	0.0638	0.0501
30.00	165	1:20	3.0	21.0	15	17.6	1.3	Yes	90.0	Head	1152	0.018	0.015	0.838	383	0.0549	0.0460
30.00	165	1:20	3.0	23.0	15	19.2	1.7	Yes	45.0	Head	1152	0.020	0.017	0.835	400	0.0576	0.0480
								Fort Fisher, NC									
4.30	165	1:55	2.00	14.7	10	11.8	4.0	Yes	90.0	Trunk	512	0.029	0.023	0.803	211	0.0697	0.0559
								St. Paul, AK									
18.00	166	1:100	2.5	27.0	14	21.2	4.3	Yes	90.0	Trunk	1004	0.027	0.021	0.785	401	0.0673	0.0529

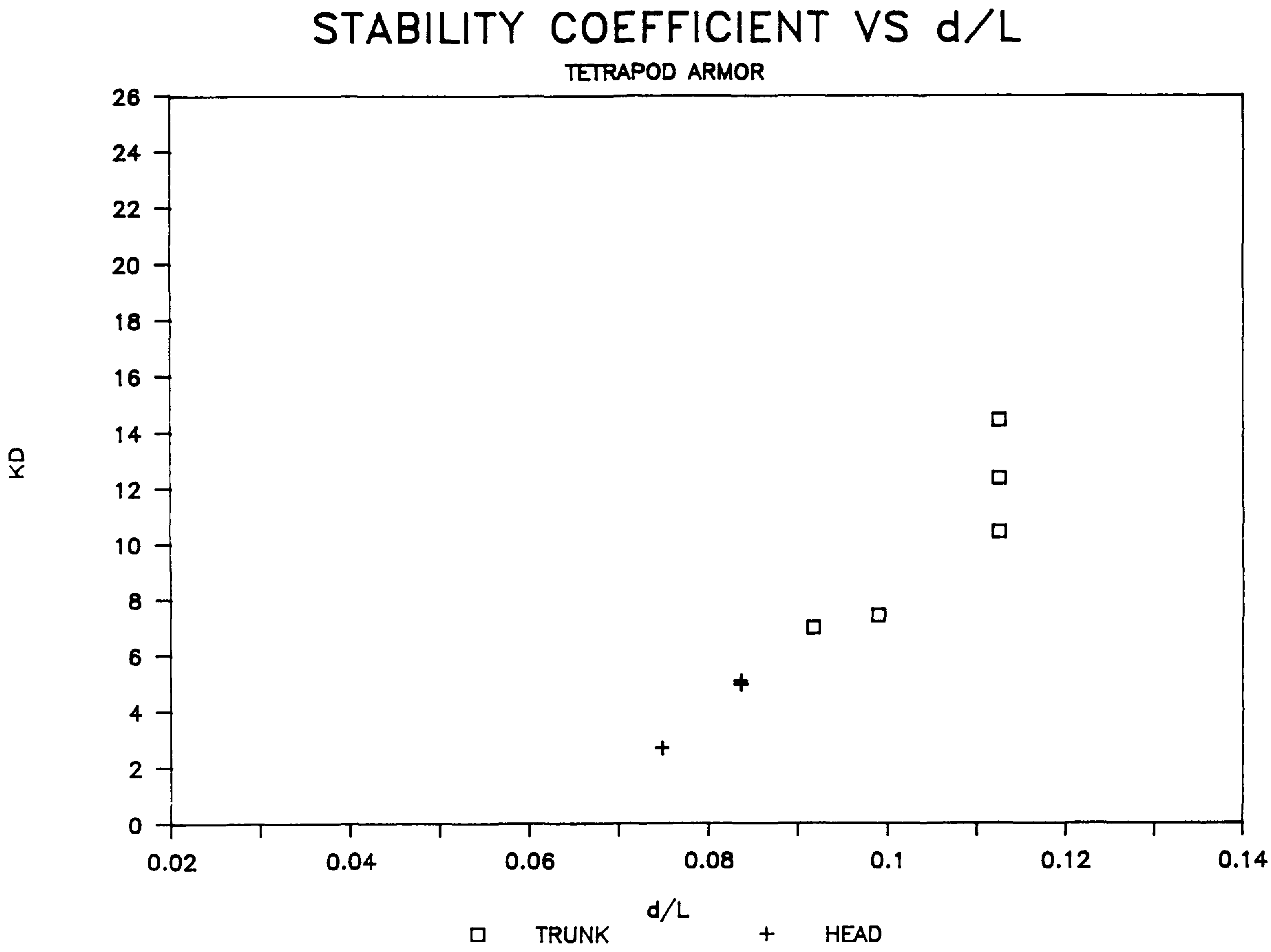

Figure 1. K_D as a function of d/L

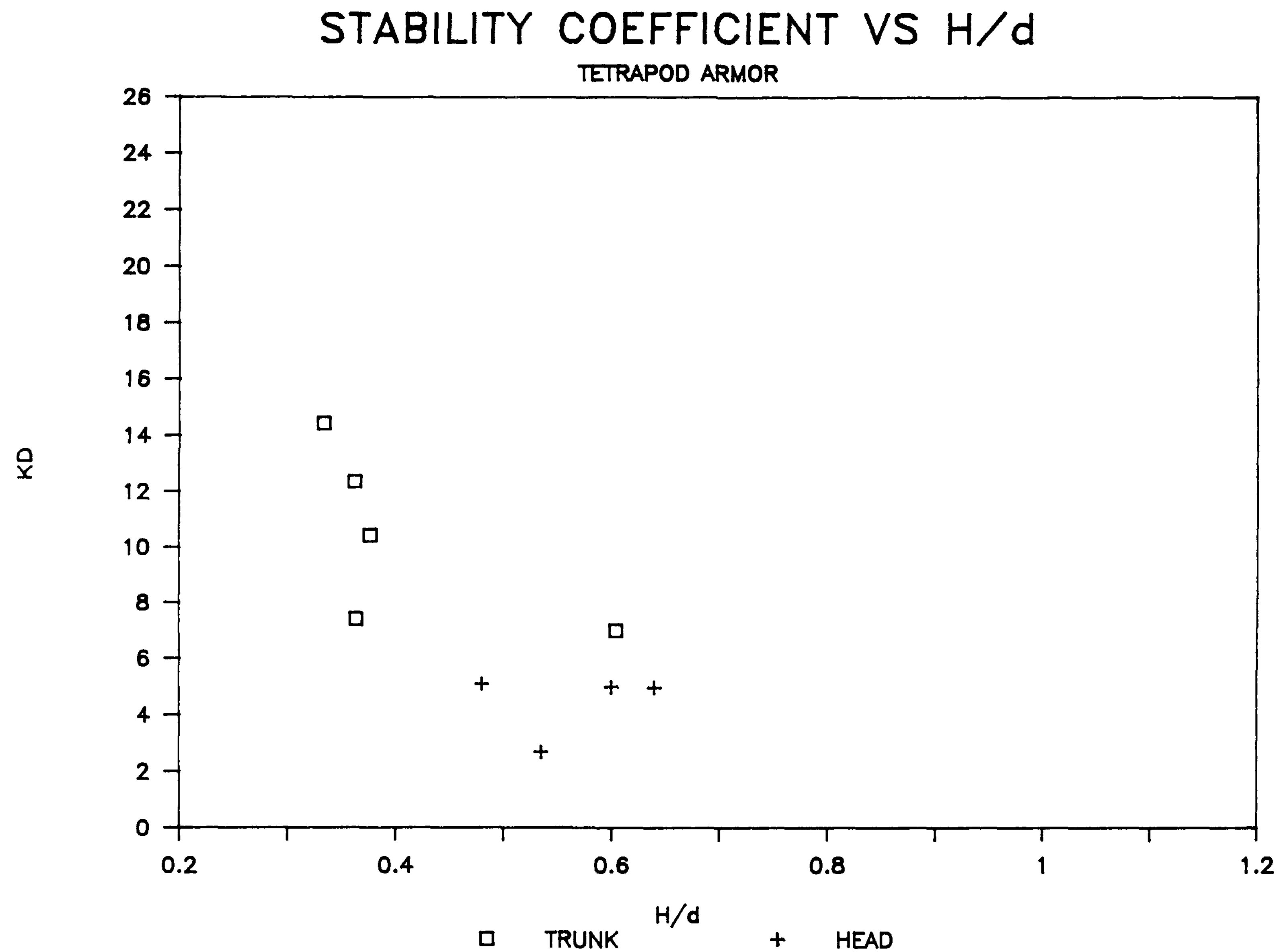

Figure 2. K_D as a function of H/d

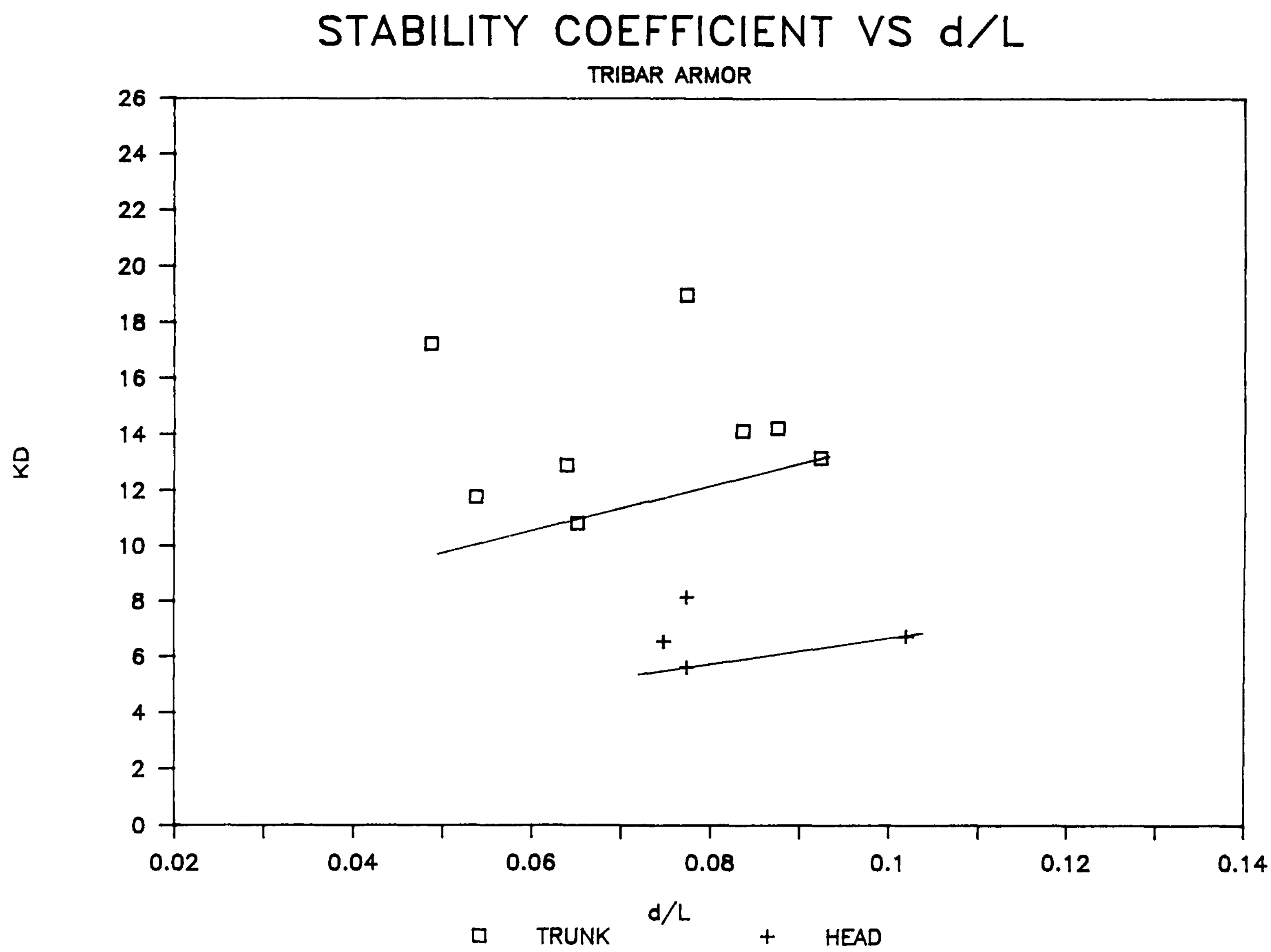

Figure 3. Tribar stability as a function of d/L

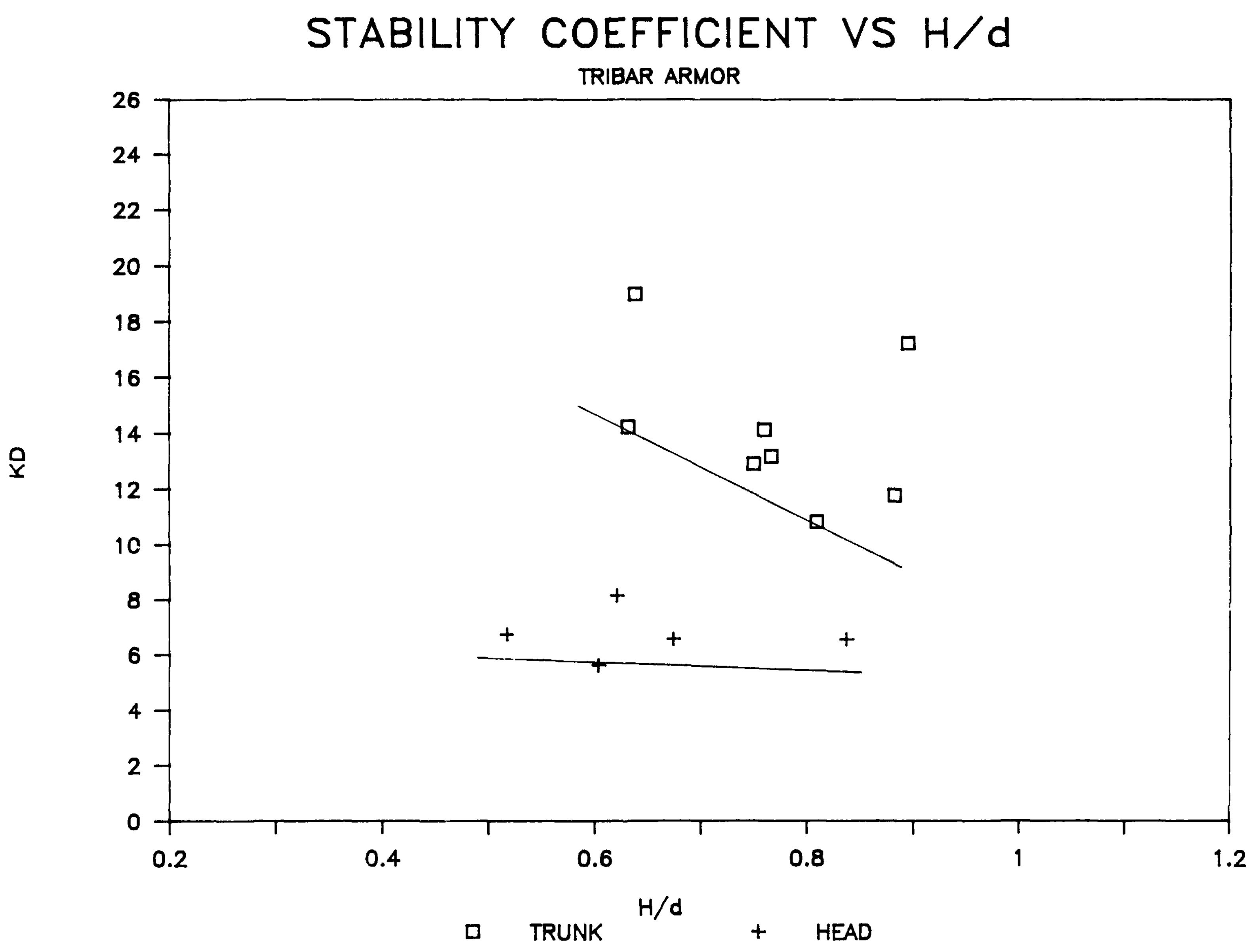

Figure 4. Tribar stability as a function of H/d

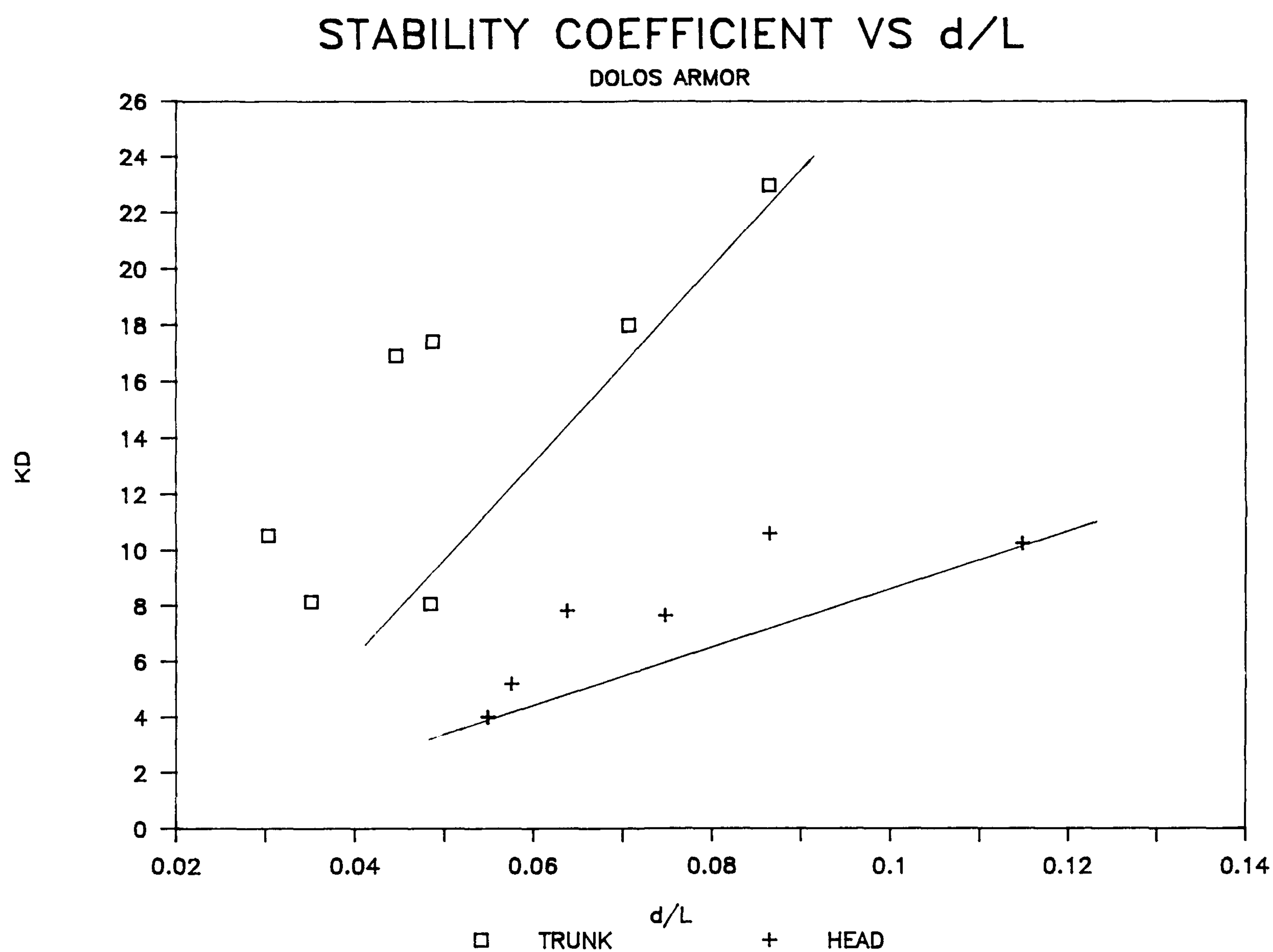

Figure 5. Dolos stability as a function of d/L

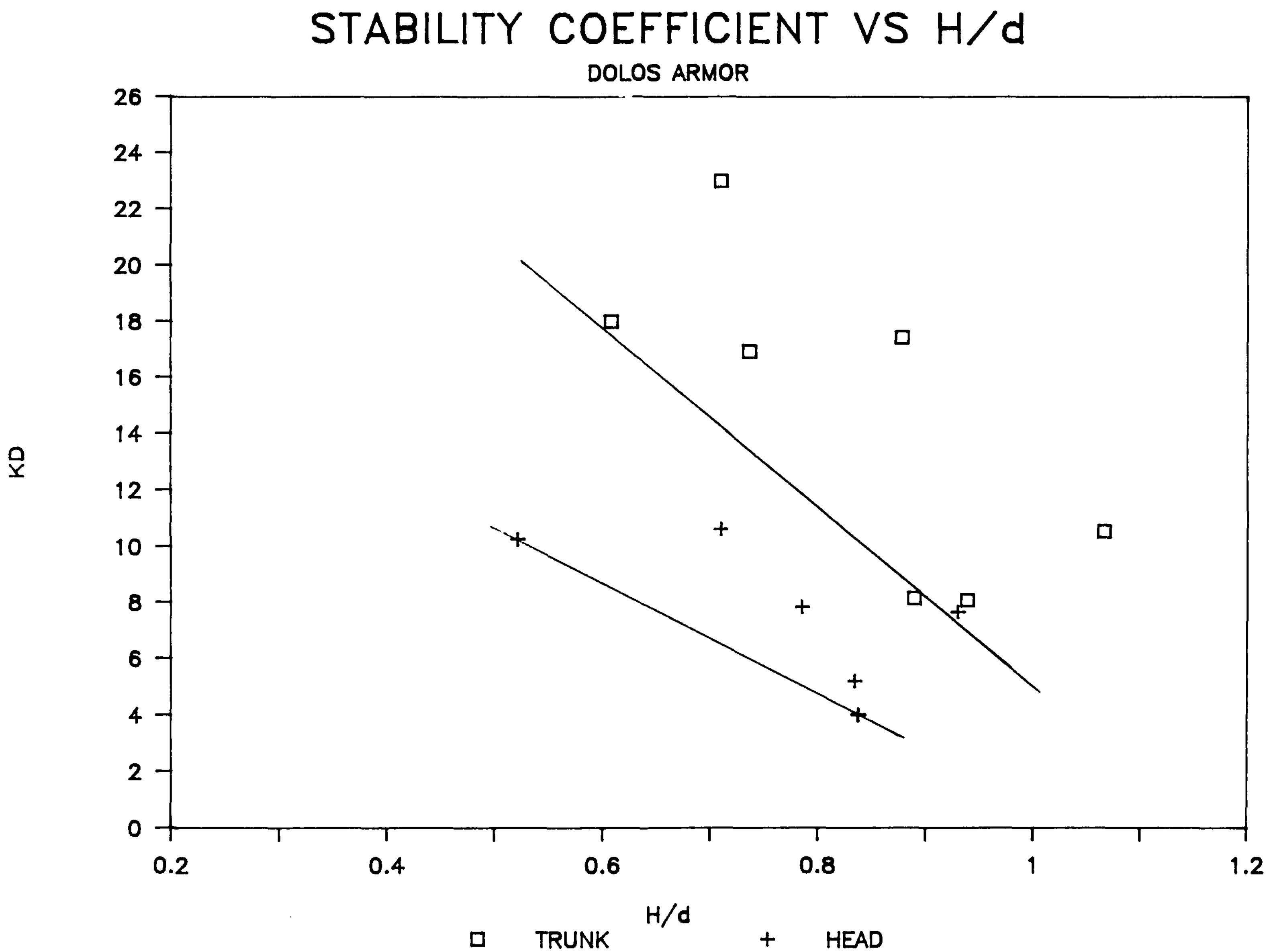

Figure 6. Dolos stability as a functioon of H/d

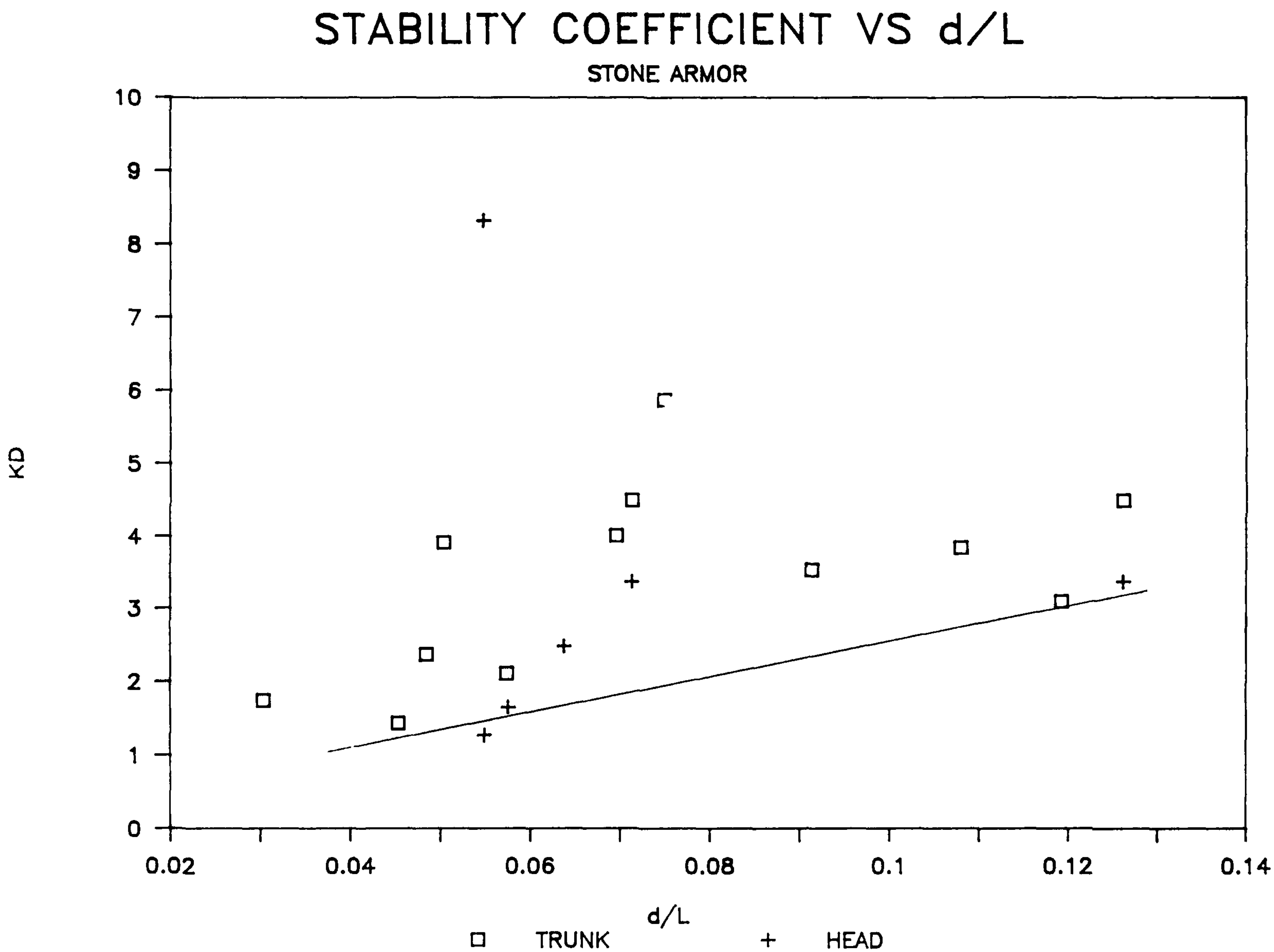

Figure 7. Stone armor stability as a function of d/L

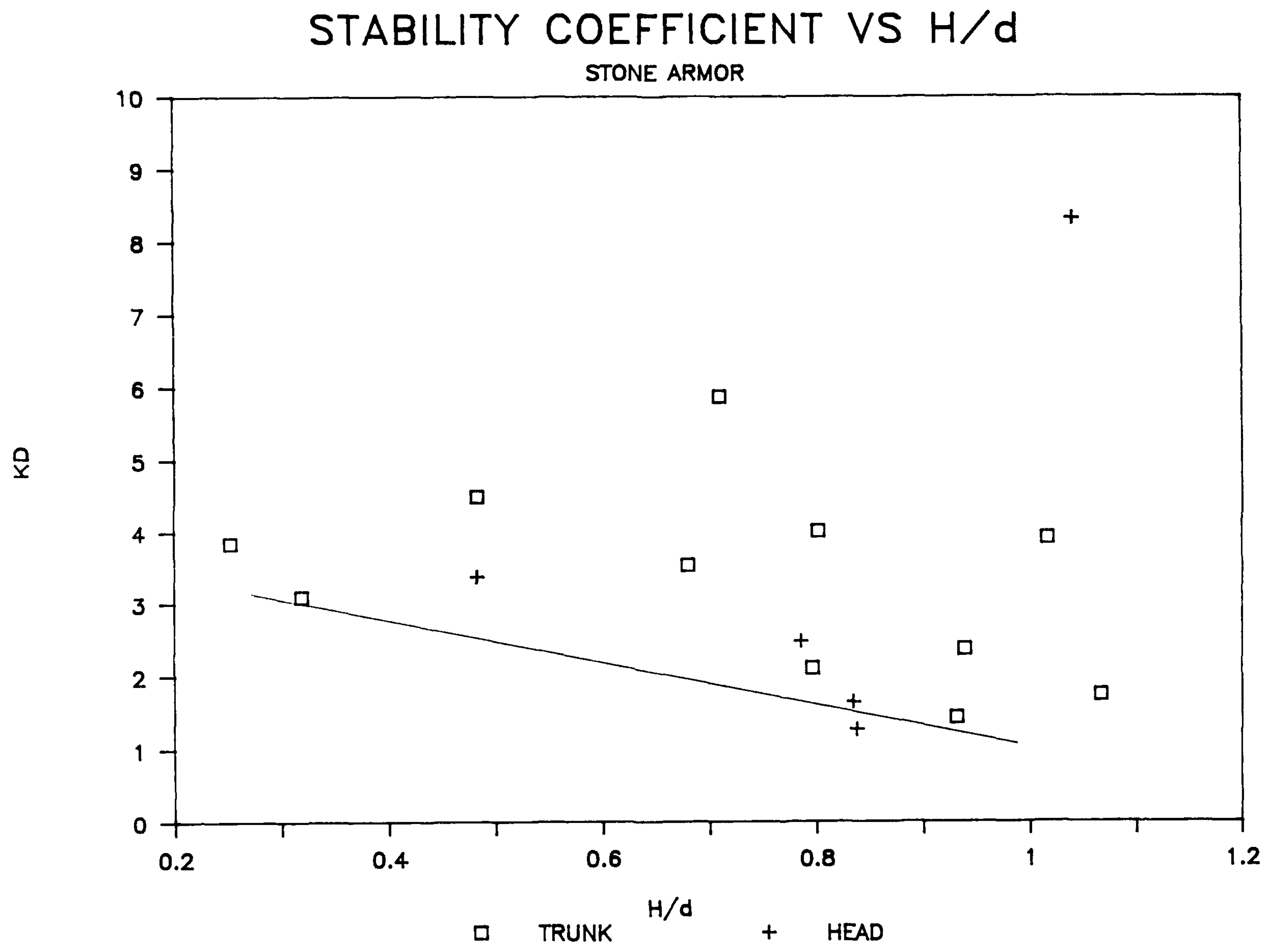

Figure 8. Stone armor stability as a function of H/d

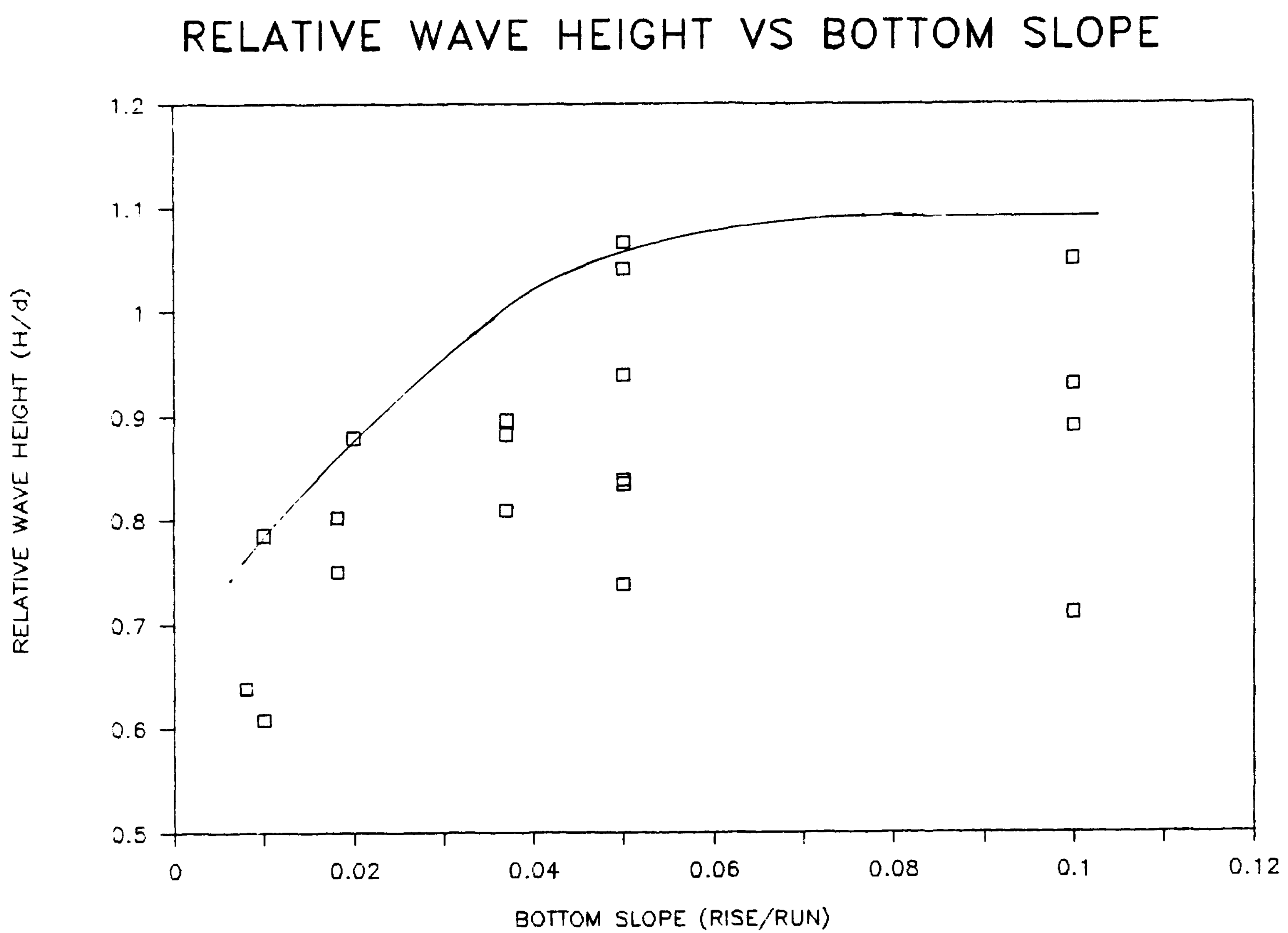

Figure 9. H/d as a function of bottom slope

APPENDIX A: NOTATION

d	Water depth, ft
d/L	Relative depth, dimensionless
g	Acceleration due to gravity, ft/sec^2
H	Wave height, ft
H/d	Relative wave height, dimensionless
K_D	Stability coefficient, dimensionless
L	Wave length at a given water depth, ft
L_o	Deepwater wavelength, ft
T	Wave period, sec
W_a	Weight of an armor unit, lb
α	Angle of breakwater slope, measured from horizontal, deg
$\cot \alpha$	Reciprocal of breakwater slope
γ_a	Specific weight of armor unit, pcf